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COMPOUND RADIOINTERFEROMETER WITH INDEPENDENT HETERODYNES FOR THE INVESTIGATION OF EMISSION SOURCES' RADIOIMAGES

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SUMMARY

The present work develops further the methods, earlier proposed by R. C. Jennison and MacPhil [2, 3] for the creation of a compound radiointerferometer with independent heterodynes, valid for the study of the angular structure of emission sources. The latter is indeed one of the fundamental problems of astrophysics.

* * *

One of the basic problems of astrophysics is the investigation of the angular structure of the emission sources. For the study of sources with small angular dimensions in the radioband, the application of radiointerferometers with independent heterodynes of high sensitivity to measurements and with practically unlimited angular resolution, is most promising, (see ref. [1]). However, because of the uncertainty of initial phases of heterodyne signals and their instability in time, a two-antenna interferometer with independent heterodynes allows us to measure only the amplitude spectrum of spatial frequencies of brightness distribution over the source, which is found to be insufficient in a series of cases.

Jennison proposed in 1958 a circuit of three-antenna radiointerferometer, allowing to determine the relative phase of two spectral components and thereby obtain a complex spectrum of spatial frequencies [2]. Subsequently, the three-antenna system was utilized in a compound-interferometer of intensities [3].

The block-diagram of the compound radiointerferometer with independent heterodynes is shown in Figure 1. The interferometer antennas A_1, A_2, A_3 are disposed along the base line at distances $A_1A_2 = S_0$, $A_2A_3 = nS_0$ ($n = 1, 2, 3..$). Antenna A_3 is movable. The receivers $П_1$ and $П_2$ are connected by a single heterodyne $Г_1$, while heterodyne $Г_2$ is used in the receiver $П_3$. The absence of high-frequency connection with receiver $П_3$ allows us the increase practically unlimitedly the distance A_1A_2. The intermediate frequency signal transmission from the receivers' output to the analyzer may be materialized by communication lines, as well as by way of signal registration by memory devices with subsequent reading information for simultaneous processing. In the last case signals from receivers $П_1$ and $П_2$ outputs are registered by a single memory device with utilization either of two-channel registration, or frequency separation. Magnetophones with corresponding compensation for the instability of the registration and reproduction.

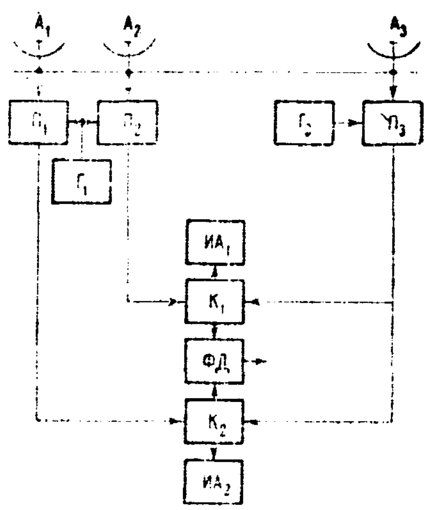

Fig.1
Block-diagram of a compound radio-interferometer:

A_1, A_2, A_3, are the antennas; $П_1$, $П_2$, $П_3$ are the receivers; $Г_1$, $Г_2$ are heterodynes; K_1, K_2 are the correlators; $ИА_1$, $ИА_2$ are the amplitude measurers. ФД is the phase detector.

Assume that the source is at an angle Θ with respect to the base line of the interferometer with angular extension W, within the bounds of which the brightness radiodistribution is given by the function $T(\Theta)$. Making use of the well known theory of the two-element interferometer (see, for example [4]), let us write the expression for the antenna temperature of a two-antenna interferometer A_2A_3 with independent heterodynes $Г_1$ and $Г_2$ at reception of the emission in the frequency band $\Delta\omega$ in the form

../...

$$T_{a_n}(\Theta) = \int_{-W/2}^{W/2} T(\Theta')\,d\Theta' + \Psi_n(\tau_n) \int_{-W/2}^{W/2} T(\Theta') \left\{\cos\left[2\pi \frac{nS_0\Theta_0}{\lambda} + \Phi(t)\right] \times \right.$$
$$\times \cos\left(2\pi \frac{nS_0\Theta'}{\lambda}\right) - \sin\left[2\pi \frac{nS_0\Theta_0}{\lambda} + \Phi(t)\right] \sin\left(2\pi \frac{nS_0\Theta'}{\lambda}\right)\Big\}\,d\Theta' =$$
$$= V_{=} + \Psi_n(\tau_n) V_{\sim n} \cos\left[2\pi \frac{nS_0\Theta_0}{\lambda} + \Phi(t) - \alpha_n\right], \qquad (1)$$

where

$$V_{=} = \int_{-W/2}^{W/2} T(\Theta')\,d\Theta'; \quad \Psi_n(\tau_n) = \frac{\sin(\Delta\omega\tau_n/2)}{\Delta\omega\tau_n/2}; \quad \tau_n = \frac{nS_0\Theta_0}{c};$$
$$V_{\sim n} = \sqrt{a_n^2 + b_n^2}; \ \mathrm{tg}\,\alpha_n = b_n / a_n;$$
$$a_n = \int_{-W/2}^{W/2} T(\Theta') \cos\left(2\pi \frac{nS_0}{\lambda}\Theta'\right) d\Theta'; \qquad b_n = \int_{-W/2}^{W/2} T(\Theta') \sin\left(2\pi \frac{nS_0\Theta'}{\lambda}\right) d\Theta'.$$

Correspbndingly, for a two-antenna interferometer A_1A_3 we shall obtain

$$T_{a_{(n+1)}}(\Theta) = V_{=} + \Psi_{(n+1)}(\tau_{(n+1)}) V_{\sim(n+1)} \cos\left[2\pi \frac{(n+1)S_0}{\lambda}\Theta_0 + \Phi(t) - \alpha_{(n+1)}\right], \qquad (2)$$

where

$$\tau_{(n+1)} = (n+1)S_0\Theta_0/c; \quad V_{\sim(n+1)} = \sqrt{a^2_{(n+1)} + b^2_{(n+1)}}; \quad \mathrm{tg}\,\alpha_{(n+1)} = b_{(n+1)}/a_{(n+1)};$$
$$a_{(n+1)} = \int_{-W/2}^{W/2} T(\Theta') \cos\left(2\pi \frac{(n+1)S_0}{\lambda}\Theta'\right) d\Theta';$$
$$b_{(n+1)} = \int_{-W/2}^{W/2} T(\Theta') \cos\left(2\pi \frac{(n+1)S_0}{\lambda}\Theta'\right) d\Theta'.$$

In the expressions (1) and (2)

$$\Phi(t) = \omega_{\Gamma_1}(t) - \omega_{\Gamma_2}(t) + \omega_0\Delta t - \omega_{\Gamma_1}\Delta t + \varphi_{\Gamma_1}(t-\Delta t) - \varphi_{\Gamma_2}(t), \qquad (3)$$

where ω_0 is the mean frequency of the received radiation; ω_{Γ_1} and ω_{Γ_2} are respectively the signal frequencies of heterodynes Γ_1 and Γ_2; $\varphi_{\Gamma_1}(t)$ and $\varphi_{\Gamma_2}(t)$ are their random phases; Δt is the relative lag of intermediate frequency signals from different receivers, either on account of interferometer shoulder assymetry, or because of imprecise reading coincidence. Δt is, in its turn, a function oi time determinable by fluctuations of electric lengths of transmission lines from the receiver to the analyzer, or by fluctuations of signal registration and reproduction by the memory devices. From expressions (1) and (2) it is not difficult to notice that the amplitudes $V_{\sim n}$ and $V_{\sim(n+1)}$ and phases α_n and $\alpha_{(n+1)}$ of "interference components" are amplitudes and phases of Fourier-transformation of brightness distribution $T(\Theta)$ for spatial frequencies nS_0/λ and $(n+1)S_0/\lambda$ respectively. For measurements of $V_{\sim n}$ and $V_{\sim(n+1)}$ amplitudes, one must necessarily have

$$\Psi(\Theta) = 1,$$

which is attained by introducing intermediate frequency lags by the times τ_n and $\tau_{(n+1)}$ into the corresponding shoulders of the interferometer. In this case the interference components of signals (1) and (2) will have the form

$$V_{\sim n}\cos\left[2\pi\frac{nS_0}{\lambda}\Theta_0 + \Phi_n(t) - \alpha_n\right], \quad (4)$$

$$V_{\sim(n+1)}\cos\left[2\pi\frac{(n+1)S_0}{\lambda}\Theta_0 + \Phi_{(n+1)}(t) + \alpha_{(n+1)}\right], \quad (5)$$

where

$$\Phi_n(t) - \Phi_{(n+1)}(t) = (\omega_0 - \omega_r)(\tau_n - \tau_{(n+1)}) = \omega_{\text{IF}}\Delta\tau.$$

The determination of $|V_{\sim n}|$ and $|V_{\sim(n+1)}|$ is conducted by the standard methods of determination of quasi-sinusoidal signals. Measurement of phases α_n and $\alpha_{(n+1)}$ does not appear to be possible; however, comparison of signals by phases allows us to determine the difference phase of spectral components of spatial frequencies nS_0/λ and $(n+1)S_0/\lambda$:

$$\varphi_n = 2\pi\frac{S_0\Theta_0}{\lambda} - \alpha_n + \alpha_{(n+1)} + \Phi_{(n+1)}(t) - \Phi_n(t).$$

The quantity $\Phi_{(n+1)}(t) - \Phi_n(t) = \omega_{\text{IF}}\Delta\tau$ can be determined with a sufficiently high precision by the calculation method, or directly measured by way of corresponding calibration of lags introduced into the shoulders of the interferometer. We may write

$$2\pi\frac{S_0\Theta_0}{\lambda} + \alpha_{(n+1)} - \alpha_n = A_n. \quad (6)$$

The quantity A_n determines the phase shift between the two above-indicated spectral components of brightness distribution over the source, shifted by an angle Θ from the normal to interferometer's base line. Changing the length of the base A_2A_3, we may determine the amplitude and the relative phase of spectral components of spatial fre uencies corresponding to various values of n, and thereby obtain the complex spectrum of radiobrightness distribution over the source. At the same time, in view of the total autonomy of the third receiving complex, a high resolution of the radiointerferometer can be achieved, which would allow us to investigate the fine angular structure of the source of radioemission.

*** T H E E N D ***

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